

# ***Magnesium, Zinc, and Chromium Nutrition and Athletic Performance***

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## **Catalog Data**

Lukaski, H.C. (2001). Magnesium, zinc, and chromium nutrition and athletic performance. *Can. J. Appl. Physiol.* 26(Suppl.): S13-S22. ©2001 Canadian Society for Exercise Physiology.

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**Key words:** *fatigue, physical training, recovery, minerals*

**Mots-clés:** *fatigue, entraînement physique, récupération, minéraux*

## **Abstract/Résumé**

*Magnesium, zinc and chromium are mineral elements required in modest amounts for health and optimal performance. Accumulating evidence supports the hypothesis that magnesium and zinc play significant roles in promoting strength and cardiorespiratory function in healthy persons and athletes. Differences in study designs, however, limit conclusions about recommendations for intakes of magnesium and zinc needed for optimal performance and function. The role of chromium in supporting performance is not well established. There is a compelling need to confirm and extend findings of beneficial effects of magnesium and zinc function and performance of humans. Suggestions for an experimental model and specific topics for research to advance knowledge of mineral nutrition to promote attainment of genetic potential for optimal performance are provided.*

*Aux fins de santé et de performance optimale, les besoins de magnésium, de zinc et de chrome sont minimes. De plus en plus d'études confirment le rôle important du magnésium et du zinc dans l'expression de la force musculaire et dans le bon fonctionnement*

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*cardiorespiratoire d'athlètes et de personnes en bonne santé. Les limites inhérentes aux devis expérimentaux nous empêchent de formuler des recommandations spécifiques concernant la ration suffisante pour atteindre une performance optimale et combler les fonctions biologiques. L'effet du chrome sur la performance n'est pas encore bien établi. De toute évidence, il faut effectuer d'autres études pour confirmer les bienfaits du magnésium et du zinc sur la performance et sur les fonctions biologiques. En plus de thèmes spécifiques de recherche, un modèle expérimental est proposé pour augmenter le corpus de connaissances sur le rôle des minéraux alimentaires dans l'atteinte de la performance optimale en conformité avec le potentiel génétique.*

## Introduction

Athletes who seek to boost performance generally rely on proper diet and increased training. With increased emphasis on the synergism between diet and training to maximize performance, there is a burgeoning awareness of the beneficial role that mineral element nutrition can play in achieving the goal of attainment of genetic potential in physical performance (Lukaski, 1999a).

In contrast to the macronutrients that are consumed in large amounts (hundreds of grams daily), micronutrients, such as magnesium, zinc and chromium, are ingested in much smaller amounts (milligrams and micrograms per day). The macronutrients provide sources of energy (carbohydrate and fat) required to fuel the body during work and recovery, maintain cellular hydration (water) and provide the body structure (protein) to perform work. Despite their relative paucity in the diet and the body, magnesium, zinc and chromium perform important roles in regulating body metabolism, including energy utilization and work performance.

The importance of these minerals is highlighted by the diversity of metabolic processes in which they exert some regulation. Magnesium, a ubiquitous element that plays a fundamental role in many cellular reactions, is involved in numerous enzymatic reactions in which food is catabolized and new chemical products are formed (Shils, 1998). Some examples include the breakdown of glycogen, fat oxidation, protein synthesis, adenosine triphosphate synthesis, and the second messenger system. Magnesium also is a physiological regulator of membrane stability and is involved in the maintenance of neuromuscular, cardiovascular, immune, and hormonal function (Shils, 1998).

Another intracellular cation, zinc, is needed for the activity of more than 300 enzymes from many species. Zinc-containing enzymes participate in many components of macronutrient metabolism and cell replication. In addition, some zinc-containing enzymes, such as carbonic anhydrase and lactate dehydrogenase, are involved in intermediary metabolism during exercise; another enzyme, superoxide dismutase, protects against free radical damage (Vallee and Falchuk, 1993).

Chromium is the recipient of considerable recent attention. Trivalent chromium is hypothesized to be necessary for the maintenance of balanced glucose metabolism in mammals; thus, chromium may act as a facilitator of insulin action (Stoecker, 1996), although the exact mechanism is unknown (Vincent, 2001). This insulinogenic characteristic of chromium has prompted the suggestion that chromium has an anabolic function and may enhance glucose utilization (Lukaski, 1999b).

This paper addresses the scientific evidence that magnesium, zinc and chromium nutrition affects performance. It examines the effects of variable intakes of

minerals (e.g., low, adequate and supplemental) on specific aspects of physiological function during controlled exercise and, where available, studies of the interaction between trace mineral nutrition and performance.

### Mineral Intakes Among Athletic Groups

Surveys of athletes reveal that intakes of certain minerals may be less than recommendations for optimal biological function. In general, athletes participating in sports that involve weight limits (e.g., wrestling) or have an aesthetic component (e.g., gymnastics and diving) tend to consume less than 70% of recommended intakes of magnesium and zinc (Chen et al., 1989; Lukaski, 2000). Because of their increased energy intakes, most male athletes tend to consume minerals in amounts that exceed the recommended amounts. Importantly, athletes involved in active weight loss or manipulation of food selection to markedly increase carbohydrate intake have mineral intakes that may be less than recommendations (Lukaski, 2000).

Estimates of chromium intakes of athletes are unavailable. The high variability in the chromium content of the same foods from different regions, a lack of data for chromium content of a wide-range of commonly consumed foods and contamination of food with chromium during processing and preparation hamper the routine assessment of chromium intake among athletes, as well as the general public (Lukaski, 1999b).

### Magnesium

Magnesium status has been related to physical performance in a few groups of athletes. Cross-sectional studies of male, collegiate athletes (Lukaski et al., 1983) and adolescent swimmers (Conn et al., 1988) identified significant correlations between peak oxygen uptake and plasma or serum magnesium concentrations. Serum magnesium, however, was not related to work capacity in untrained subjects. Among the athletes, the highest values of aerobic capacity were associated with circulating magnesium values at the low end of the range of normal values. Dietary magnesium was a significant predictor of improvement in 100-yd swim performance of male and female collegiate swimmers (Lukaski, 1995). Thus, these early findings suggested practical relationships among magnesium nutritional status, functional capacity and performance.

Magnesium supplementation of physically active individuals improved metabolic responses to training and during exercise (Table 1). Young men participated in a double-blind trial, consumed either their usual diets or received a magnesium supplement and initiated a 7-wk strength training program (Brilla and Haley, 1992). Peak knee-extension torque significantly increased in the supplemented compared to the placebo group.

Magnesium supplementation also improved cardiorespiratory function during exercise (Table 1). Physically-active men (Ripari et al., 1989) and collegians (Brilla and Gunther, 1995) experienced significantly reduced heart rate, decreased oxygen uptake or increased endurance time, and decreased oxygen uptake during submaximal exercise, respectively, with magnesium supplementation compared to placebo. Although these findings suggest that increased magnesium intake

**Table 1 Magnesium (Mg) Intake and Work Performance or Responses to Exercise**

Source	Sample	Mg Treatment, mg/d	Mg Effects
Brilla & Haley, 1992	Men	250 vs 507	↑ strength
Ripari et al., 1989	Men	250 vs 450	↓ heart rate, ↓ ventilation
Brilla & Gunther, 1995	Men, women	290 vs 540	↓ O <sub>2</sub> use, ↓ ventilation, ↑ endurance time
Golf et al., 1993	Men	Placebo vs 360	↓ O <sub>2</sub> use
Lukaski & Nielsen	Women	153 vs 322 or 360	↓ O <sub>2</sub> use, ↓ ventilation, ↓ heart rate

promotes beneficial physiological effects and performance, they do not indicate which individuals would benefit from additional magnesium.

Studies of persons with low magnesium status clearly show the benefit of increased magnesium intake on physiological function during exercise. Elite male rowers with serum magnesium concentrations at the low end of the range of normal values used significantly less oxygen during a submaximal rowing ergometer test after magnesium supplementation compared to placebo (Golf et al., 1994). Also, postmenopausal women responded with normalized serum magnesium, reduced oxygen use, decreased heart rate, and improved ventilatory function during submaximal ergocycle exercise when they consumed 322 or 360 compared to 153 mg of magnesium daily (Lukaski and Nielsen, 2001). Thus, persons, regardless of physical activity level (e.g., trained vs untrained), with decreased magnesium nutritional status exhibit reduced physiological strain during exercise when magnesium intake is increased.

## Zinc

Severe zinc deficiency adversely affects skeletal muscle function. *In situ* and *in vitro* experiments have shown the importance of zinc for skeletal muscle performance and resistance to fatigue (Isaacson and Sandow, 1963; Richardson and Drake, 1979). Increasing evidence indicates that zinc status affects performance (Table 2).

Various human studies confirm the importance of zinc in muscle function and strength. In a double-blind cross-over study, 16 women received either 135 mg zinc daily or placebo for 14-d periods with a similar washout period (Krotkiewski et al., 1982). Zinc supplementation significantly increased dynamic (isokinetic) strength at 180 degrees/sec of angular velocity and isometric endurance. Neither muscle strength nor endurance were affected by placebo treatment. Serum zinc

**Table 2 Zinc (Zn) Intake and Performance Measures**

Source	Sample	Zn Treatment, mg/d	Zn Effects
Krotkiewski et al., 1982	Women	Placebo vs 135	↑ muscle strength, ↑ endurance
Van Loan et al., 1999	Men	0.3 vs 12	↑ total work
Lukaski et al., 1999	Men	3 vs 18	↑ peak O <sub>2</sub> & CO <sub>2</sub>

concentrations of 20 female and male adolescent gymnasts were significantly reduced compared to non-athletic, age- and sex-matched controls; serum zinc was significantly correlated with isometric adductor strength (Brun et al., 1995). Male professional football players with low serum zinc concentrations had significantly decreased peak power output and increased blood lactate concentrations during peak ergocycle tests (Khaled et al., 1997).

Controlled feeding studies extend the findings of impaired physiological function with decreased zinc status. Van Loan et al. (1999) found decreased total work capacity in knee extensor and shoulder extensor and flexor muscles of men after they consumed 0.3 mg compared to 12 mg zinc provided in a formula diet. Plasma zinc concentration decreased significantly with zinc deprivation; neither plasma zinc nor strength improved with short-term (3 wk) zinc repletion.

Zinc depletion adversely affects cardiorespiratory function during exercise (Lukaski et al., 1999). Physically active but untrained men were fed diets composed of western foods and containing either 3 or 18 mg zinc in a double-blind, cross-over experiment. Peak oxygen use and carbon dioxide output decreased significantly and ventilation increased significantly with low dietary zinc. Also, heart rate, oxygen consumption and ventilatory rate increased significantly, while carbon dioxide output decreased significantly during submaximal exercise when the low-zinc diet was consumed. Zinc retention (e.g., intake - urinary and fecal losses) and plasma zinc concentrations decreased significantly with the low zinc diet. Red blood cell carbonic anhydrase activities (total and isozymes I and II) decreased significantly when the low zinc diet was consumed. These findings contrast with a previous report of no effect of dietary zinc restriction on exercise metabolism in sedentary men fed 4 and 34 mg zinc daily (Lukaski et al., 1984). However, neither zinc retention nor plasma zinc was affected in the previous study. Thus, low dietary zinc and reduced zinc status adversely affect muscle strength and cardiorespiratory function during exercise in humans.

### Chromium

Although chromium supplementation has been proposed to enhance muscle accretion and fat loss (Anderson, 1998), studies of chromium (Cr<sup>+3</sup>) supplementation and exercise in humans have yielded equivocal results. With the exception of the

initial positive findings of Evans (1989), there has been no consistent report of supplemental chromium, as chloride, picolinate or nicotinate, as a promoter of weight and fat loss with a concomitant increase of muscle or fat-free mass in humans (Table 3). Two studies designed to determine the interaction of chromium supplementation and exercise on weight loss in men and women found no effect of chromium, independent of exercise (Grant et al., 1997; Trent and Theiding-Cancel, 1995). In addition, none of the studies designed to evaluate the interaction of chromium and exercise on body composition (Table 3) found any performance enhancement attributable to chromium *per se*.

Chromium supplements have been evaluated as an adjunct to boost the effects of carbohydrate-electrolyte drink on performance during intermittent high-intensity

**Table 3 Effects of Supplemental Chromium (Cr) and Exercise on Body Composition and Performance of Humans**

Source	Subjects	Cr Supplement, $\mu\text{g/d}$	Exercise	Cr Effect
Evans, 1989	Men	CrPic <sup>1</sup> (200)	Resistive	$\uparrow$ FFM <sup>2</sup>
Evans, 1989	Men	CrPic (200)	Resistive	$\uparrow$ FFM, $\downarrow$ % fat
Hasten et al., 1992	Men & women	CrPic (200)	Resistive	$\downarrow$ Body circumferences
Clancy et al., 1994	Men	CrPic (200)	Resistive	No effects
Trent et al., 1995	Men & women	CrPic (200)	Aerobic	No effects
Lukaski et al., 1996	Men	CrPic, CrCl <sub>3</sub> (170-180)	Resistive	No effects
Hallmark et al., 1996	Men	CrPic (200)	Resistive	No effects
Grant et al., 1997	Women	CrPic, CrNic	Aerobic	$\uparrow$ Weight
Kaats et al., 1996	Men & women	CrPic (200, 400)	Sedentary	$\uparrow$ BCI <sup>3</sup>
Kaats et al., 1998	Men & women	CrPic (400)	Variable	$\downarrow$ Weight, $\downarrow$ fat <sup>4</sup>
Campbell et al., 1999	Men	CrPic (924)	Resistive	No effects

<sup>1</sup>CrPic = chromium picolinate; CrCl<sub>3</sub> = chromium chloride; CrNic = chromium nicotinate

<sup>2</sup>FFM = fat-free mass

<sup>3</sup>BCI = body composition index based on self-reported energy expenditure

<sup>4</sup>Dual x-ray absorptiometry assessment adjusted for self-reported energy expenditure

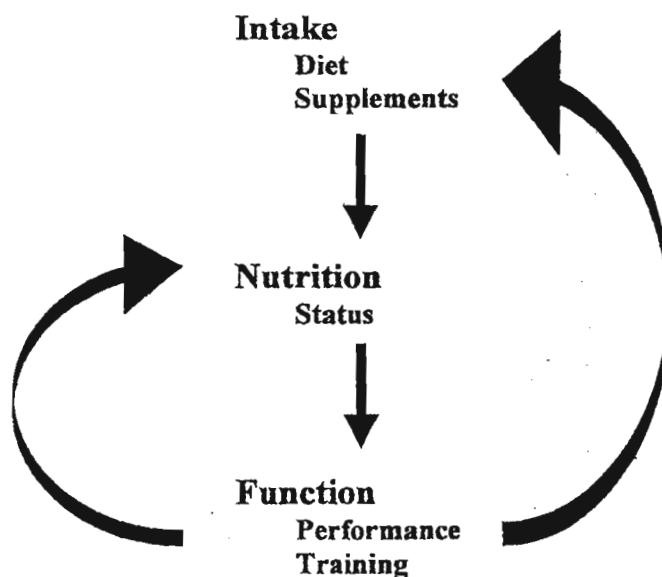
exercise (Davis et al., 2000). As compared to a flavored, placebo drink, a carbohydrate-electrolyte drink alone or with supplemental chromium (200  $\mu\text{g}$  chromium as chromium picolinate) administered twice during the test significantly increased the time to fatigue during a shuttle run. There was no independent effect of chromium, compared to the carbohydrate-electrolyte drink alone, in attenuating the onset of fatigue or the maintenance of blood glucose concentrations during the intermittent exercise test. Thus, there is no conclusive evidence to support an anabolic or ergogenic effect of supplemental chromium.

### Directions for Future Research

Despite knowledge of the basic biochemical and physiological functions of magnesium, zinc and, to some extent, chromium, there is a paucity of information describing the impact of graded intakes of these minerals on either physiological responses during exercise or performance measures. This deficit may be explained by the use of inconsistent experimental designs. One remedy is the use of a standardized research paradigm such as shown in Figure 1. This model examines the multiple interactions and feedback loops that provide a continuum between mineral intake and outcome (e.g., function), including biochemical assessment of nutritional status.

Based on review of previous research, some general suggestions to improve studies to evaluate the effect of mineral nutrition on function and performance may be proposed. The immediate need is to confirm and extend previous findings of beneficial effects of adequate compared to restricted mineral intake:

- Assess nutrient intake and objective measure(s) of mineral nutritional status when examining function and performance either in the laboratory or during competition. Is there a relationship between performance measures and biochemical indicators of mineral nutrition status?



**Figure 1.** Interactions among nutrient intake, status and function.

- Conduct feeding or supplementation trials to evaluate the effects of graded intake of minerals on physiological function or performance. Do luxuriant intakes of minerals affect performance or nutritional status?
- Identify biomarkers of mineral intake and status. Is low intake of a specific mineral related to a non-performance function, such as mental (e.g., depression or concentration) or immune function?
- Characterize mechanism(s) of altered function or performance by using animal models as well as human volunteers. Do changes in the activity or amount of mineral-containing enzymes or proteins correspond to performance measures or physiological function?

The question of optimal mineral intake is germane not only to athletes but also to the general population. National organizations that make recommendations for nutrient intakes emphasize the need for research to establish nutrient requirements based on functional outcomes, including health (Food and Nutrition Board, 2001). There also is a need to determine mineral needs of persons throughout the life-cycle including children, adolescents and the elderly. With the growing awareness of the world-wide public health problem of obesity and the recommendations to increase physical activity and modify diet to combat overweight, information on mineral needs to attain these goals is needed.

As stated so eloquently by Goethe, "Knowing is not enough; we need to apply. Willing is not enough; we need to do." This tenet will serve us well as we strive to acquire data to make recommendations for the intakes of minerals to promote health, well-being and performance.

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**Revue Canadienne de  
Physiologie Appliquée**

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Volume 26, Supplément, 2001

**Canadian Journal of  
Applied Physiology**

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Volume 26, Supplement, 2001

Proceedings of the 1st International Meeting

of the

**Congress on Nutrition and Athletic Performance**

at

The Shaw Conference Centre  
Edmonton, Alberta, Canada

August 8-11, 2001

**Editor/Rédacteur: Terry E. Graham**

**Publisher/Editeur: Rainer Martens**

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The *Canadian Journal of Applied Physiology / Revue Canadienne de Physiologie Appliquée* (ISSN 1066-7814) is published six times a year in Feb., April, June, Aug., Oct., and Dec. by Human Kinetics Publishers, Inc., 1607 N. Market St., Champaign, IL 61820-2200. Annual subscription rates in Canada and the U.S. are \$113.42 (Can.) and \$59 (U.S.) for individuals, and \$341.33 (Can.) and \$192 (U.S.) for institutions. Graduate student rates of \$79.18 (Can.) and \$39 (U.S.) each year available for up to 3 yrs; along with payment, indicate name of institution, year in university, and supervisor's name. CSEP members may choose to subscribe to the journal through their membership dues. Periodical postage paid at Champaign, IL. POSTMASTER: Send address changes to *Canadian Journal of Applied Physiology*, Human Kinetics, Box 5076, Champaign, IL 61825-5076.

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